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DEVELOPMENT OF HTPB PROPELLANT FOR BALLISTIC MISSILES

Grant Thompson, et al

Thiokol Corporation

Prepared for:

Air Force Rocket Propulsion Laboratory

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This is the eighth Quarterly Progress Report prepared by Thiokol Corporation, Wasatch Division, Brigham City, Utah, on the work accomplished on Contract F04611-72-C-0048 during January through March 1974.

Dr. Grant Thompson is the Principal Investigator and Mr. E. E. Day is the Program Manager. The AFRPL Project Engineer is Mr. Wayne E. Roe (MKPA).

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

For the Commander
Charles R. Cooke

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Motor static test

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents Thiokol's eighth quarter progress on Contract F04611-72-C-0048. The program objective is to develop a family of solid propellants based on HTPB (hydroxyl terminated polybutadiene) binder, and demonstrate one optimized propellant formulation by large scale motor testing. Phase I data on DL-H271, an analog of TP-H1136, showed exceptionally fine structural properties after 27 months of aging at 75° and 135°F. Additional data is presented for Phase II aging. The TU775/03 structural test vehicle was instrumented and cast with TP-H1139 propellant.

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FIGURES

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FIGURES (Cont)

TABLES

TABLES (Cont)

I. INTRODUCTION

This report presents Thiokol's eighth quarter progress on Contract F04611-72-C-0048, "Development of HTPB Propellant for Ballistic Missiles." The program objective is to develop a family of solid propellants for ballistic missiles based on an HTPB (hydroxyl terminated polybutadiene) binder, and demonstrate one optimized propellant formulation by large scale motor firings.

Specifically, five propellants have been formulated and are being characterized to the point that they will be ready for motor advanced development programs. These five propellants are compatible with two optimized missile systems: (1) a weight constrained small diameter three stage ballistic missile, and (2) a length constrained large diameter ballistic missile. In addition, a formulation which is typical of the entire series was fully defined, characterized, and demonstrated in the static firing of a Third Stage Minuteman III motor.

Significant tasks include missile optimization study and formulation tailoring plus definition of all aspects of processing, casting, storing, and handling this family of propellants. Ingredient specifications, processing instructions, and quality control procedures will be prepared. Clear identification of delivered propellant performance capability will be a major program objective. Two additional Minuteman III motors will be instrumented and loaded as structural test vehicles.

II. PHASE I - PROPELLANT CHARACTERIZATION

A. Initial Mechanical Properties and Aging

After 27 months of aging of DL-H271 (early analog of TP-H1136) propellant at 75° and 135° F, uniaxial tensile tests have once again demonstrated the excellent storage stability of this propellant. The data presented in Table 1 and Figures 1 and 2 show that strain capacities are almost the same as the original values. Significantly, since the stress capability has increased during storage, the overall structural capability of the propellant has increased. Uniaxial tensile tests will be conducted again on the aged DL-H271 propellant at three and five years.

B. Alternate Polymer (R-45R)

The fourth month of aging at both 77° and 135° F has been completed for the alternate polymer propellant (DL-H306, Mix 8737001). All testing has been completed, and the results are reported in Table 2. The data show approximately the same aging trends as previous HTPB propellant mixes. The DL-H306 propellant data will be analyzed at the eight month aging time using an aging trend analysis previously used to compare the other Phase I HTPB propellants.

III. PHASE II - SCALE-UP

Mechanical Properties and Aging

Additional mechanical properties aging data for the 90 percent solids propellant TP-H1135, Mix Number 8577001, are presented in this report. The uniaxial tensile data (Tables 3 and 4 and Figures 3 to 8) for propellant aged eight months at 77° and 135° F indicate that virtually no changes in mechanical properties have occurred between the four month testing internal (reported previously) and the eight month interval. The propellant strain capability remains excellent. Biaxial tensile data (Tables 5 and 6 and Figure 9) from the TP-H1135 propellant aged 4 and 8 months at 77° and 2, 4 and 8 months at 135° F indicate that stress levels are higher than originally, but strain capability is diminished very little (see Figure 9). The relaxation modulus data (Tables 7

to 11 and Figures 10 to 14) for these same testing intervals indicate that an increase in relaxation modulus level has also occurred during storage of the propellant at 77° and 135° F.

IV. PHASE III - DEMONSTRATION

Effort has been completed, and reported in Quarterly Progress Report Number 7, AFRPL-TR-74-4.

V. PHASE IV - AGING

A. Instrumentation

All originally planned case mounted instrumentation was installed in the TU-775/03 (Aerojet configuration) motor. Typical internal gage placement is seen in Figure 15 while external markings and cabling details are photographed on Figure 16. Gage locations, installation procedures, and checkout criteria were coordinated with Aerojet and with H. Leeming and Associates through visits to the Wasatch Division by Messrs Robert Steele and William Briggs, respectively. The gages were subjected to a zero shift and temperature compensation cycle by pressurizing to 0, 5, 10, and 15 psig while at 60° F, 80° F, and 135° F in Thiokol's environmental conditioning facility.

At the recommendation of Dr. H. Leeming and with USAF technical concurrence, the motor was returned to the instrumentation building for installation of additional gages. Experience in the Flexible Case-Grain Integration Program indicated a need for two more shear gages, to respond to circumferential motion at the chamber barrel centerline during vibration. Also needed are redundant shear and normal stress gages on the forward boot bulb (hinge) to assure data acquisition during rapid pressurization. The extra gages were taken from the Government-furnished inventory, which necessitates slipping instrumentation of the TU-775/02 (Thiokol configuration) motor until replacement gages are available. A normal stress gage (N 12) and shear gage (S 15) were mounted along with a thermocouple (T 17) on the forward boot bulb (hinge) at the 0° radial location. Shear gages at 0° and 270° were mounted in the barrel center to respond to motion in the circumferential direction during

vibration. Four of the Bond Failure gages had developed open circuits, which were repaired by cutting away IBT-115B covering the gage "feet" and then electrically joining the feet and solid copper leads with a drop of "Eccobond" brand silver loaded conductive epoxy. Wiring was added on the case wall, completion circuits were mounted in the junction boxes, and connectors and cables expanded to match. Five extra switches were mounted on the readout panel to accommodate the gage circuits. Figure 17 shows the "as-built" gage installation, as defined by Thiokol Drawing 7U46167-02. Installation contemplated for the TU-775/02 ("Thiokol" configuration) is shown on Figure 18.

The zero shift and temperature compensation checkout procedure was then repeated. The motor was conditioned at 60, 80, and 135° F on successive nights, and the chamber pressurized to 0, 5, 10, and 15 psig during gage readout.

B. Propellant

The agreement between AFRPL and Thiokol Corporation to load an 88 percent solids propellant (TP-H1139) into the Phase IV motors, rather than TP-H1135, required a new standardization of propellant. Accordingly, five one-gallon mixes of TP-H1139 propellant were made at various NCO/OH ratios to permit selection of the ratio to be used for the motor loadings.

The propellant formulations and the 2 in/min uniaxial properties are given in Table 12. The mix at the 0.775 NCO/OH ratio produced an abnormally high stress propellant and thus was made a second time. The second mix at this ratio resulted in a propellant stress more in line with the other standardization mixes. The propellant minimum stress values are plotted versus the NCO/OH ratios in Figure 19. A regression line through all of the points indicates than an NCO/OH ratio of 0.761 should produce the targeted maximum stress of 130 psi. Because this is so close to the 0.760 ratio used in one of the one-gallon standardization mixes, that composition (number 5 of Table 12) was selected for use in the motor loadings.

C. Motor Processing

The motor was cleaned and buffed as needed, and coated internally with Chemlok 234 on 22 February 1974. Following 3 days drying at 180° F, it was brush-lined with UF-2155. The motor was cast with 7418 lbs of TP-H1139 (88% solids, 20% aluminum) on 1 March 1974. The first batch of propellant was sized at 5500 lb, of which 1500 lb was supplied to Contract F04611-71-C-0049 to cast 147 cartons for Chemical Structural Aging Effects studies. The second batch of 4000 lbs was used to complete the motor casting and to prepare liner boxes.

Two thermocouples were immersed in the motor aft end casting dam to read propellant history during cure and during cooldown. Teflon tape-wrapped wooden dowels positioned the junctions 7 inches from the aft bolt circle, under about 13 inches of propellant in the dam. Another thermocouple was taped to one dowel to read circulating air temperature. All were read on a multi-point recorder for four days. As seen on Figure 20, little evidence of a vigorous exotherm was detected. The recorder was reactivated during cooldown to help evaluate continuing cure effects from slow heat loss by the large mass of propellant (Figure 21).

D. Fore-End Curing Anomaly

The motor was cured at 135° F for 216 hours starting at 2000 hours on 10 March, and the bell lid removed on the 11th. The motor cooled until 2000 hours on the 14th, when the casting dam and core were pulled with essentially nominal Minuteman forces. Some soft propellant bits were noticed sticking to the fore end of the core where it meets the fin-formers. One fin-former was removed with difficulty, and another partially disassembled. When several areas of partially cured propellant were seen around the fins, the operation was halted. Although extremely stiff, the spots were clearly plastic in nature, rather than rubbery, and could be indented readily with finger pressure.

After a series of tests and investigations, it was concluded that the first 300-500 pounds of the batch cast into the motor fin area was irregularly contaminated. The contamination was flushed out as further propellant flowed, and the remainder of the grain was unaffected. The contamination cannot be positively identified, but water in the transfer hopper is suspected as the most likely source.

Since the propellant flaws are confined to the section of the motor in the forward dome surrounded by the flexible boot (flap), negligible impact on the capability of the motor to provide good instrumented data is predicted. Gages along the sidewall and aft dome are remote enough that their readings will be unaffected. Relief of fore-end strains and shear forces is accomplished by the boot, and no strain capability is required of the adjacent propellant.

VI. SCHEDULE

Activity planned for the next quarter includes continued mechanical property testing of aged propellant from both Phases I and II.

The TU-775/03 motor will have the remaining fin formers removed, x-rays taken, and the initial gage readings taken. The motor will be raised to 135° F for six days to attempt further cure of the fore end, and to provide an added data point.

Pending receipt of contract modifications, the TU-775/02 motor processing will be suspended.

FIGURE 1

MAXIMUM STRESS VS. AGING TIME OF DL-H271

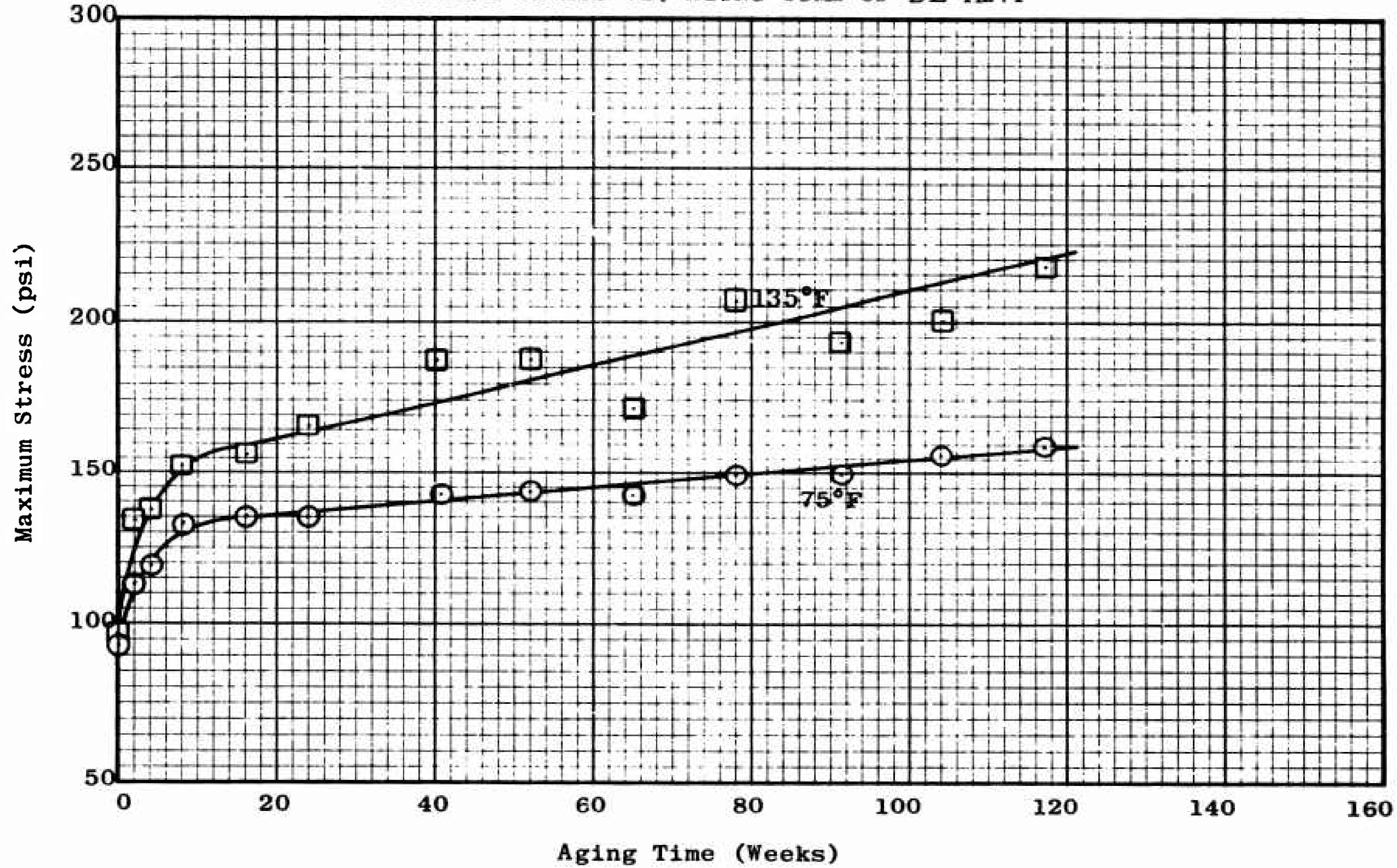


FIGURE 2

STRAIN AT MAXIMUM STRESS VS. AGING TIME OF DL-H271

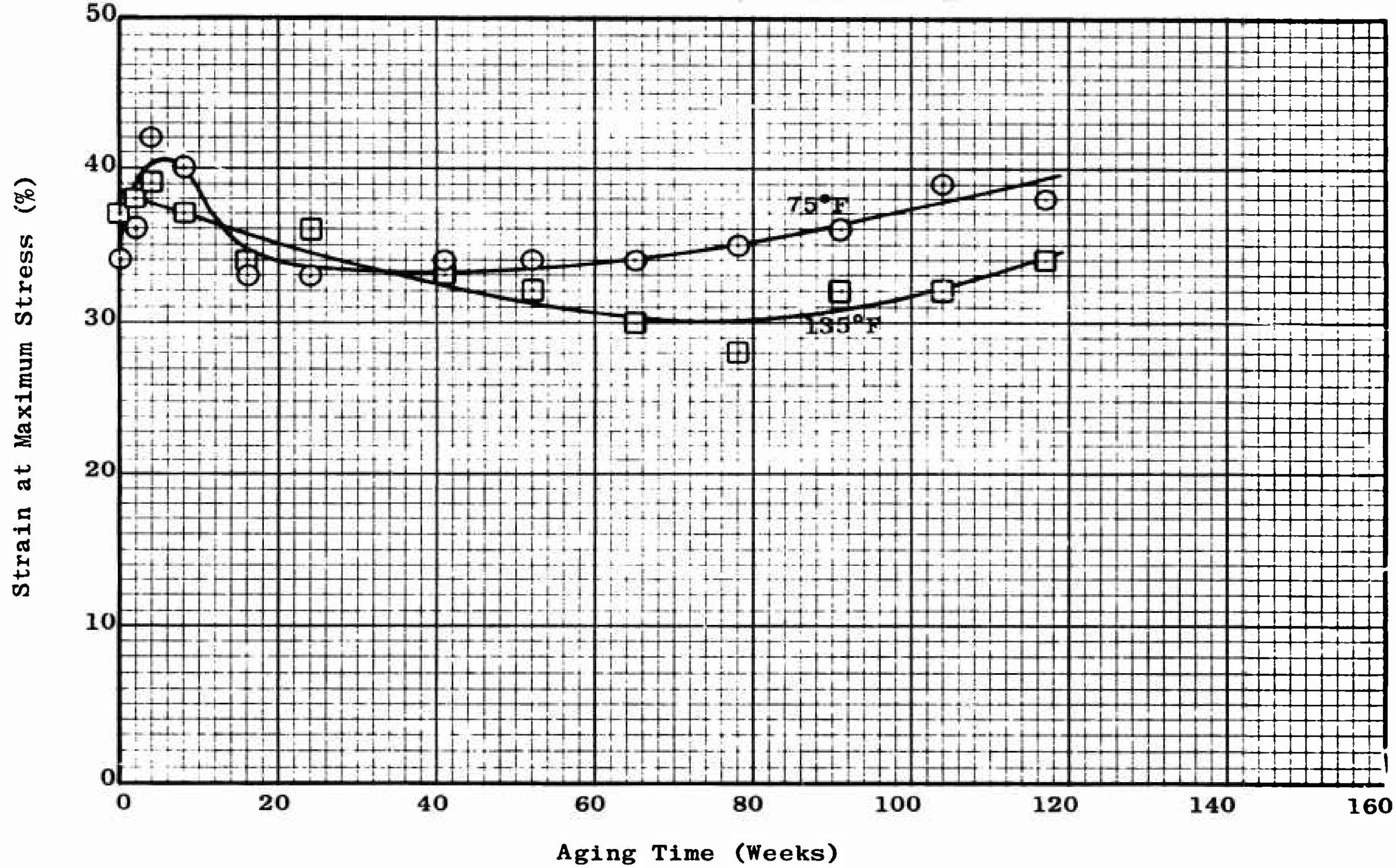


Figure 3. Failure Envelope of TP-H1135 Propellant
Mix 8577001 Aged 8 Months at 77° F

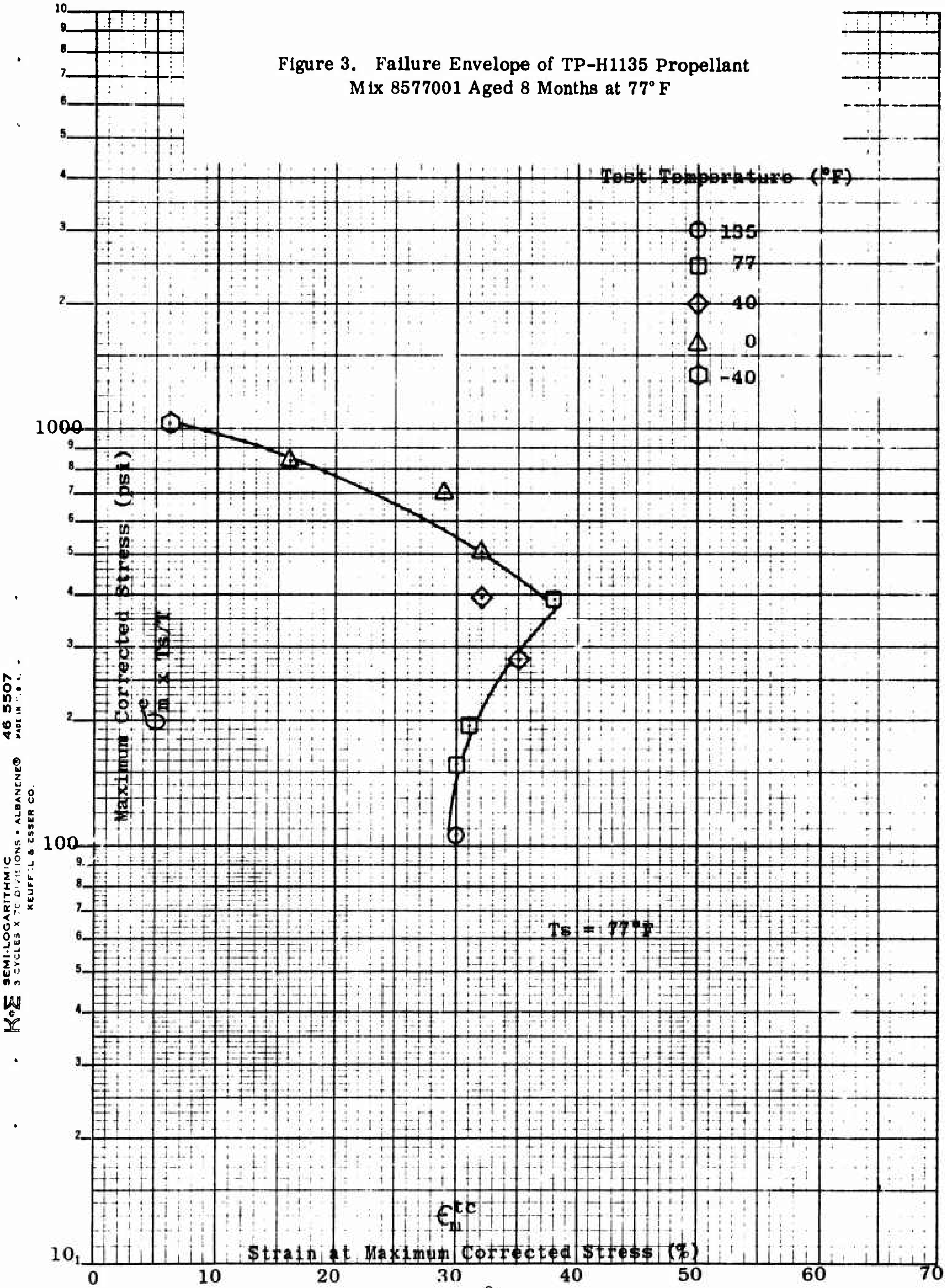
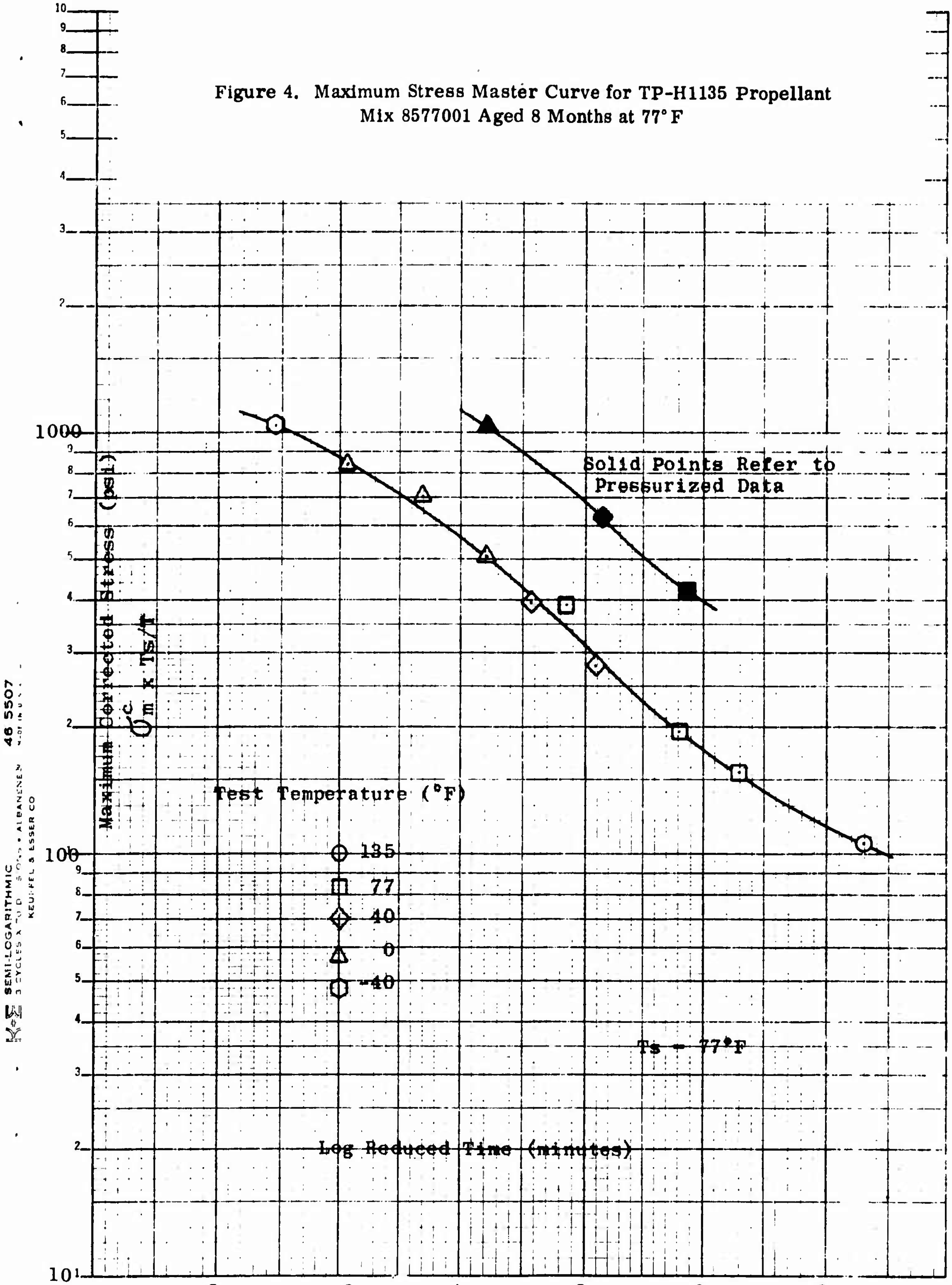


Figure 4. Maximum Stress Master Curve for TP-H1135 Propellant Mix 8577001 Aged 8 Months at 77° F



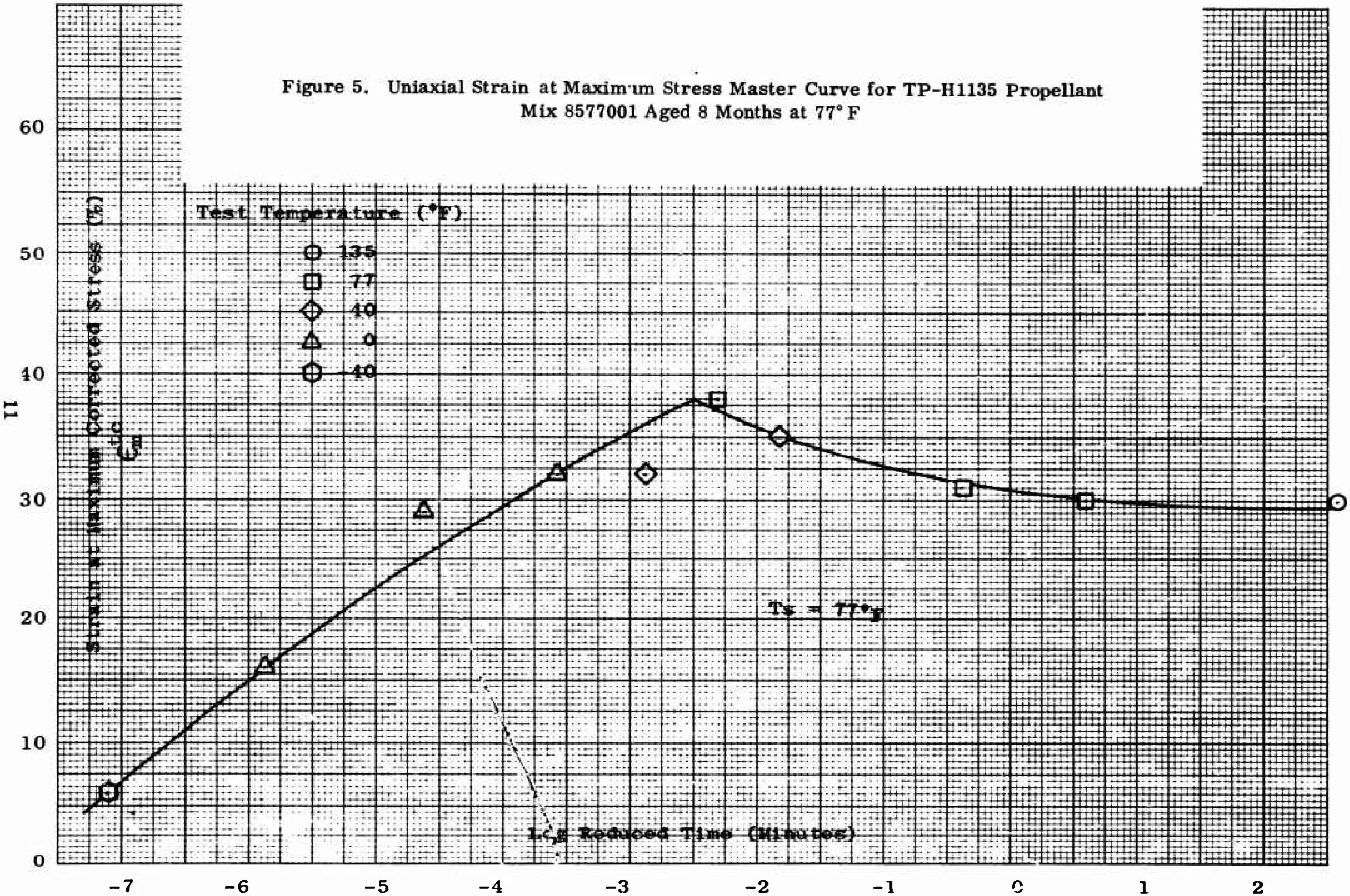


Figure 5. Uniaxial Strain at Maximum Stress Master Curve for TP-H1135 Propellant Mix 8577001 Aged 8 Months at 77° F

Figure 6. Failure Envelope of TP-H1135 Propellant
Mix 8577001 Aged 8 Months at 135° F

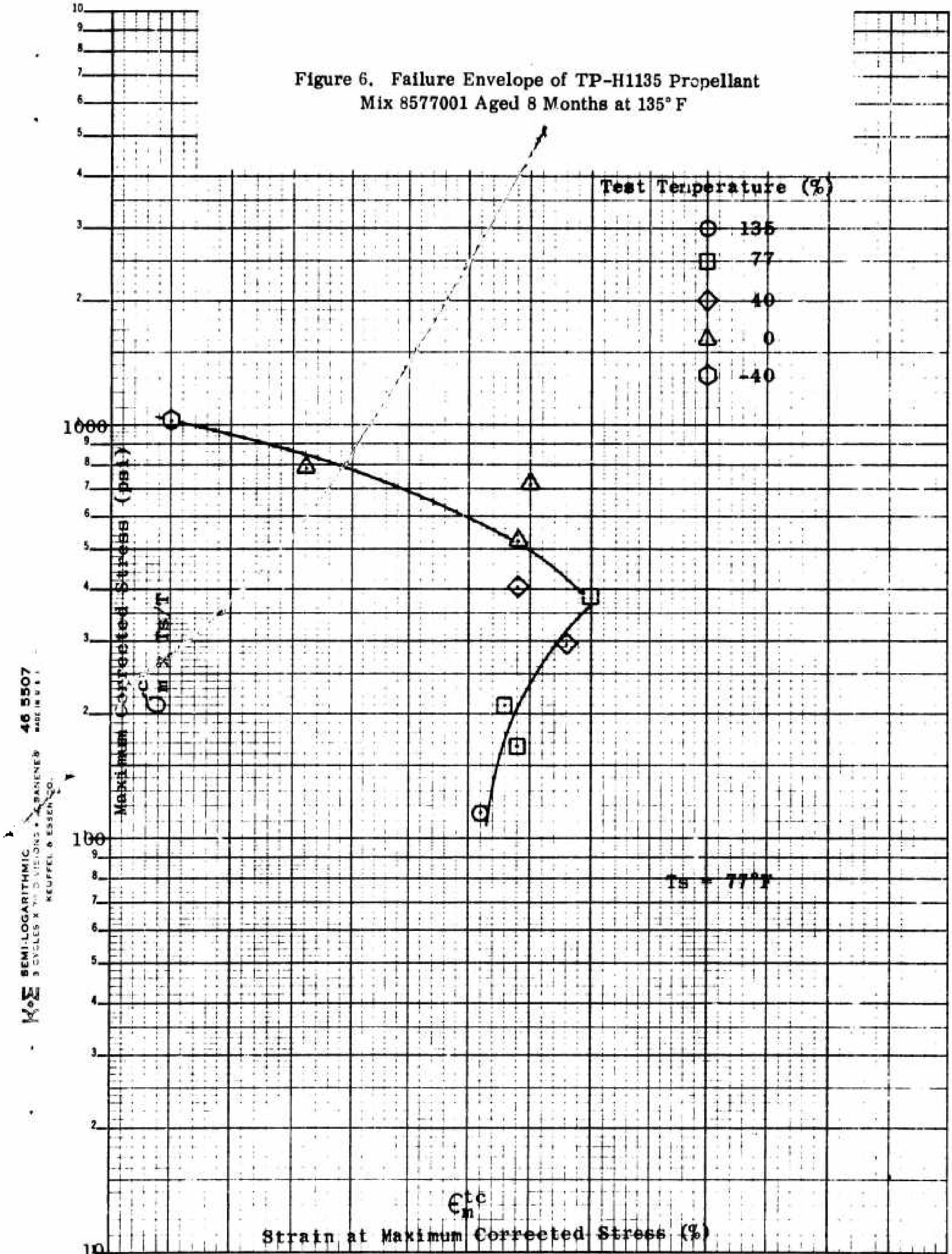


Figure 7. Maximum Stress Master Curve for TP-H1135 Propellant
Mix 8577001 Aged 8 Months at 135° F

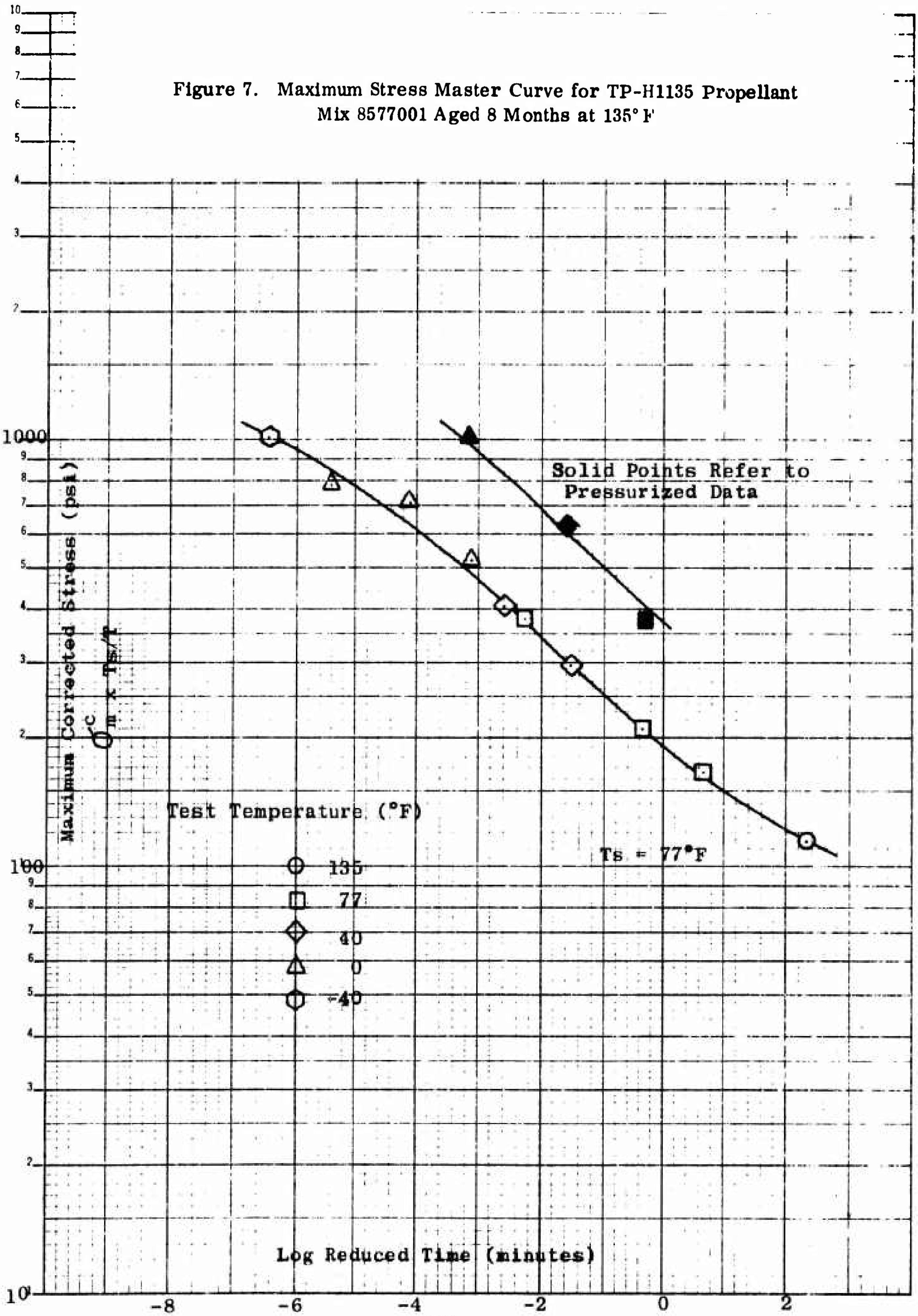
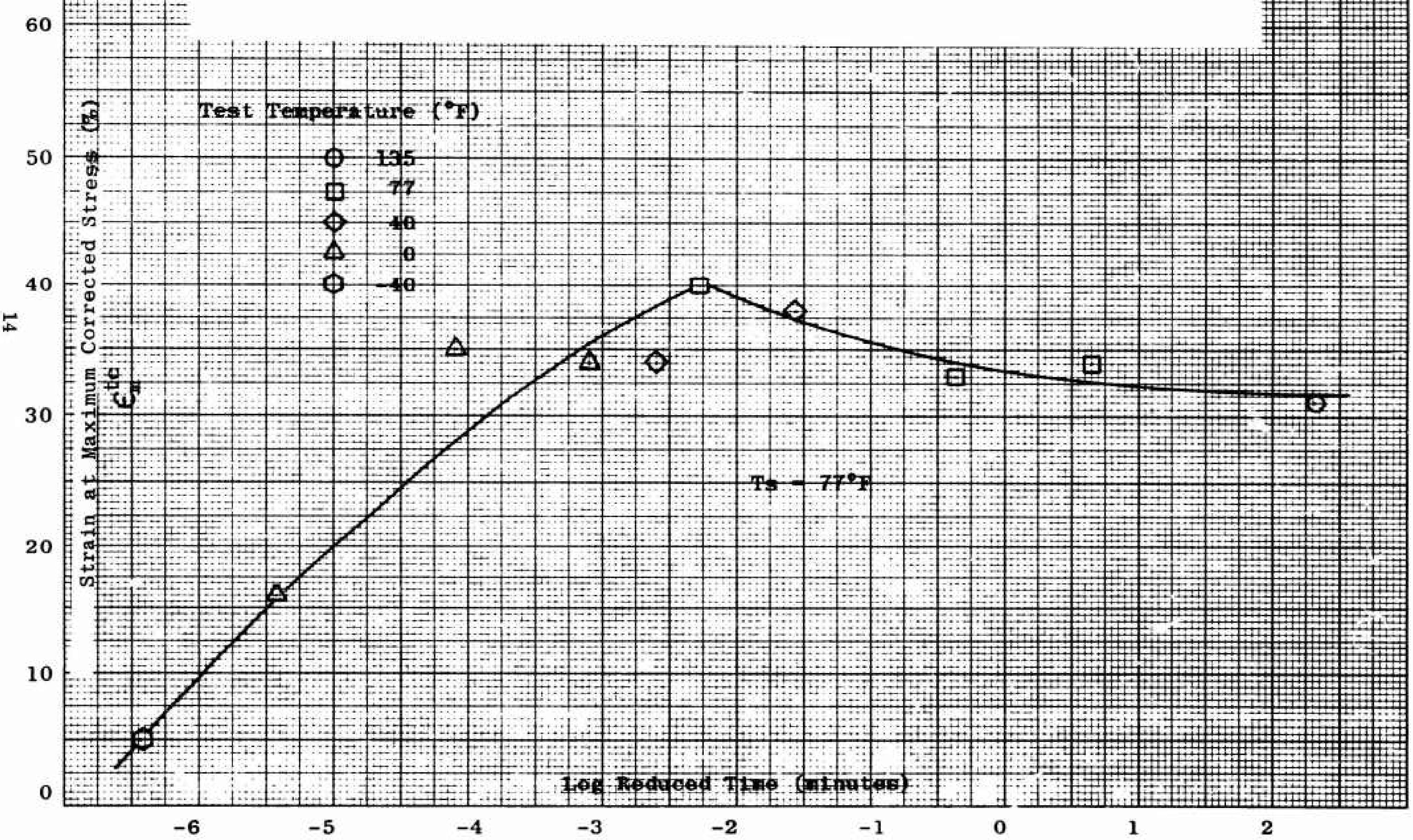


Figure 8. Uniaxial Strain at Maximum Stress Master Curve for TP-H1135 Propellant Mix 8577001 Aged 8 Months at 135° F



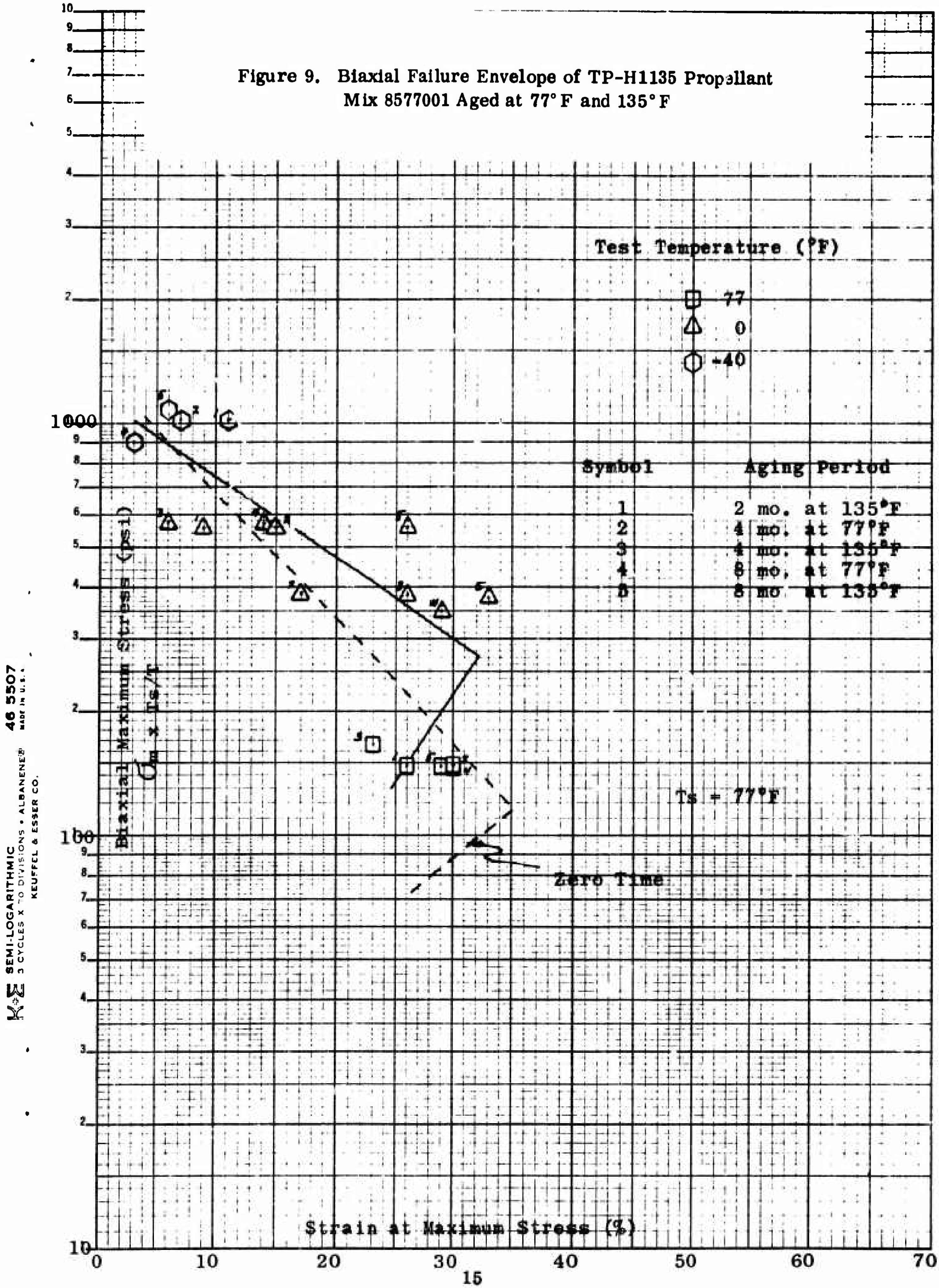


Figure 9. Biaxial Failure Envelope of TP-H1135 Propellant
Mix 8577001 Aged at 77° F and 135° F
Test Temperature (°F)
77
0
-40
Symbol
Aging Period
1 2 mo. at 135°F
2 4 mo. at 77°F
3 4 mo. at 135°F
4 8 mo. at 77°F
5 8 mo at 135°F
Biaxial Maximum Stress (psi)
$\sigma_m \times Ts/T$
Ts = 77°F
Zero Time
Strain at Maximum Stress (%)
SEMI-LOGARITHMIC
3 CYCLES X 70 DIVISIONS
ALBANENE
KEUFFEL & ESSER CO.
46 5507
MADE IN U.S.A.

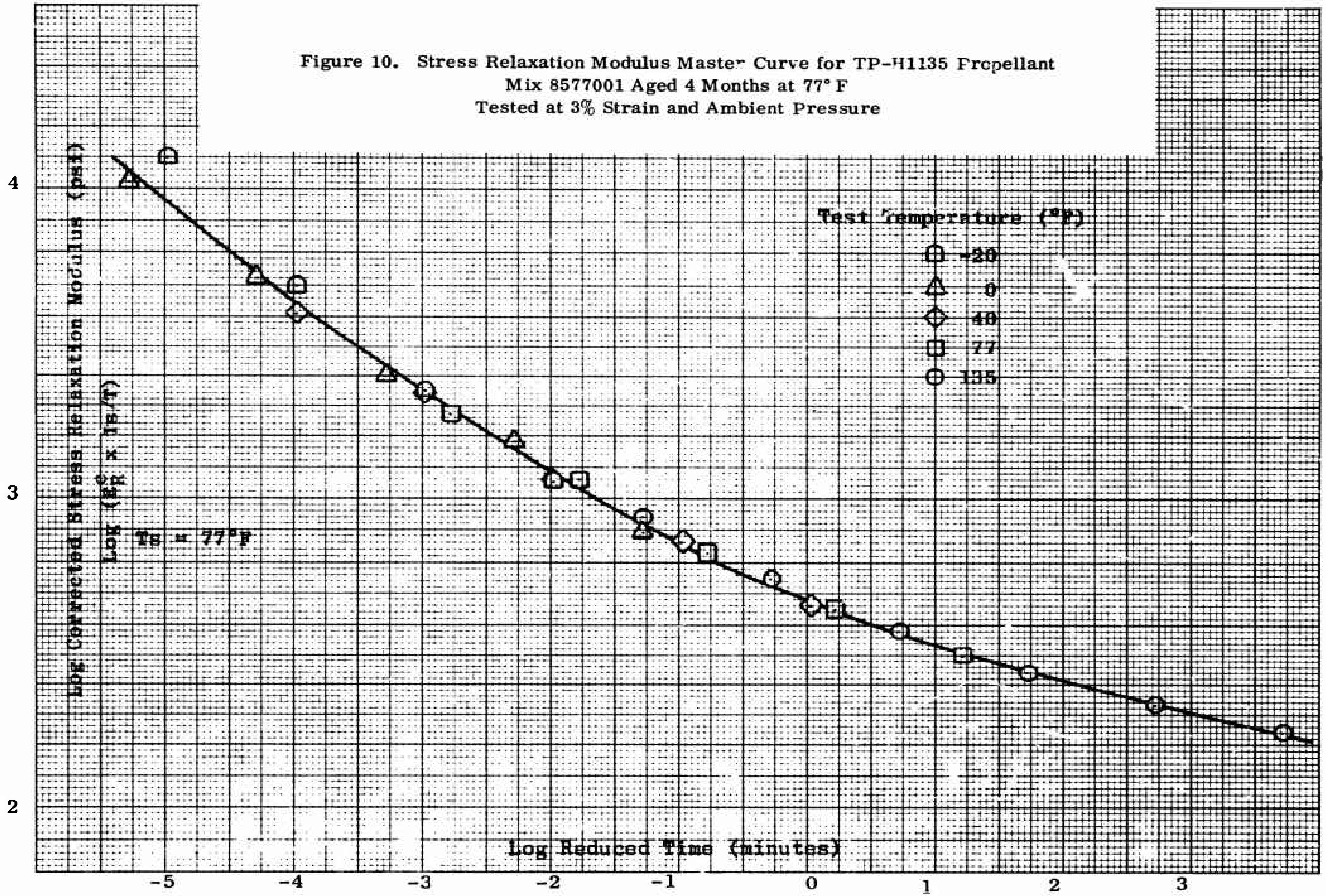


Figure 10. Stress Relaxation Modulus Master Curve for TP-H1135 Propellant
Mix 8577001 Aged 4 Months at 77° F
Tested at 3% Strain and Ambient Pressure

Figure 11. Stress Relaxation Modulus Master Curve for TP-H1135 Propellant
Mix 8577001 Aged 8 Months at 77° F
Tested at 3% Strain and Ambient Pressure

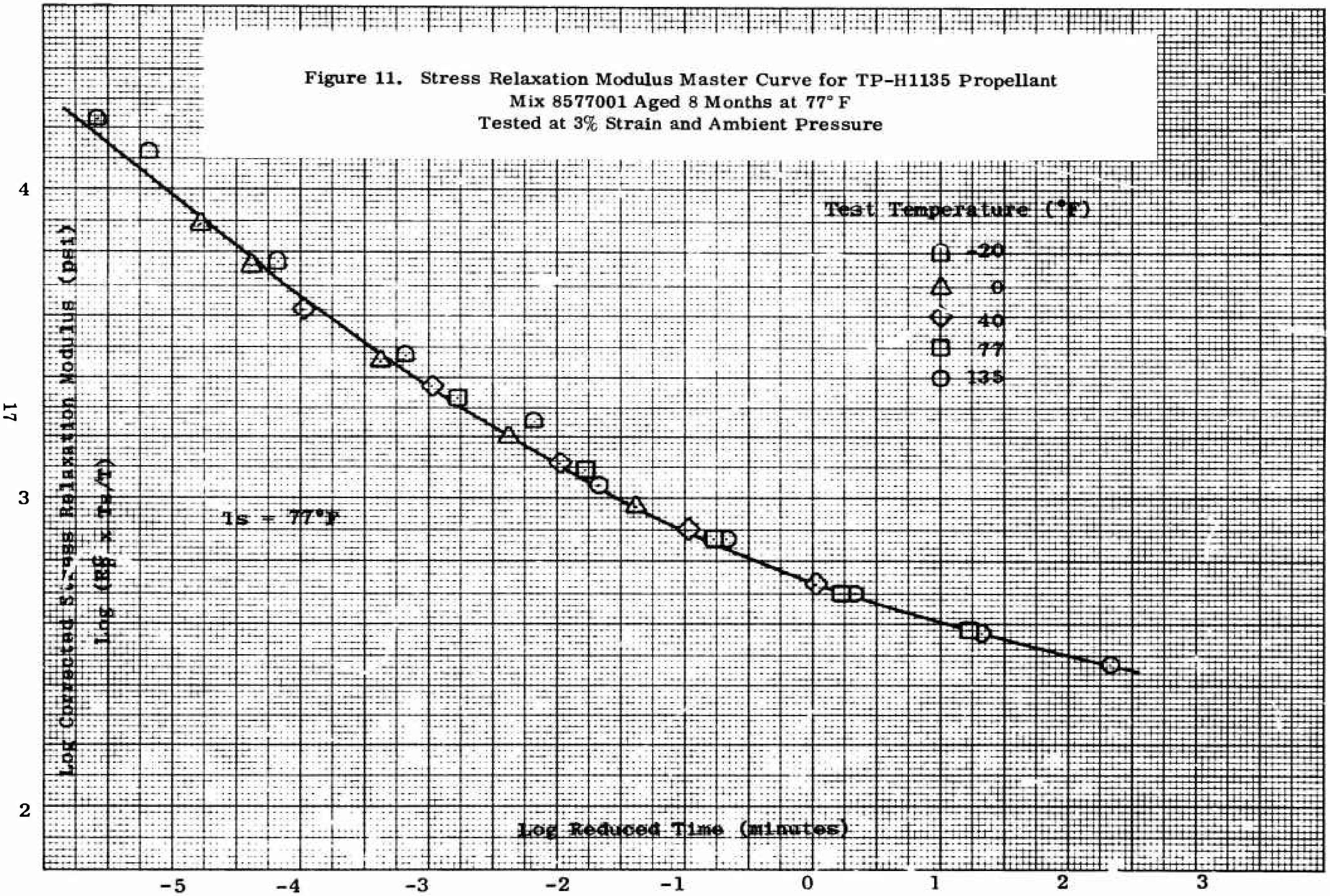


Figure 12. Stress Relaxation Modulus Master Curve for TP-H1135 Propellant
Mix 8577001 Aged 2 Months at 135° F
Tested at 3% Strain and Ambient Pressure

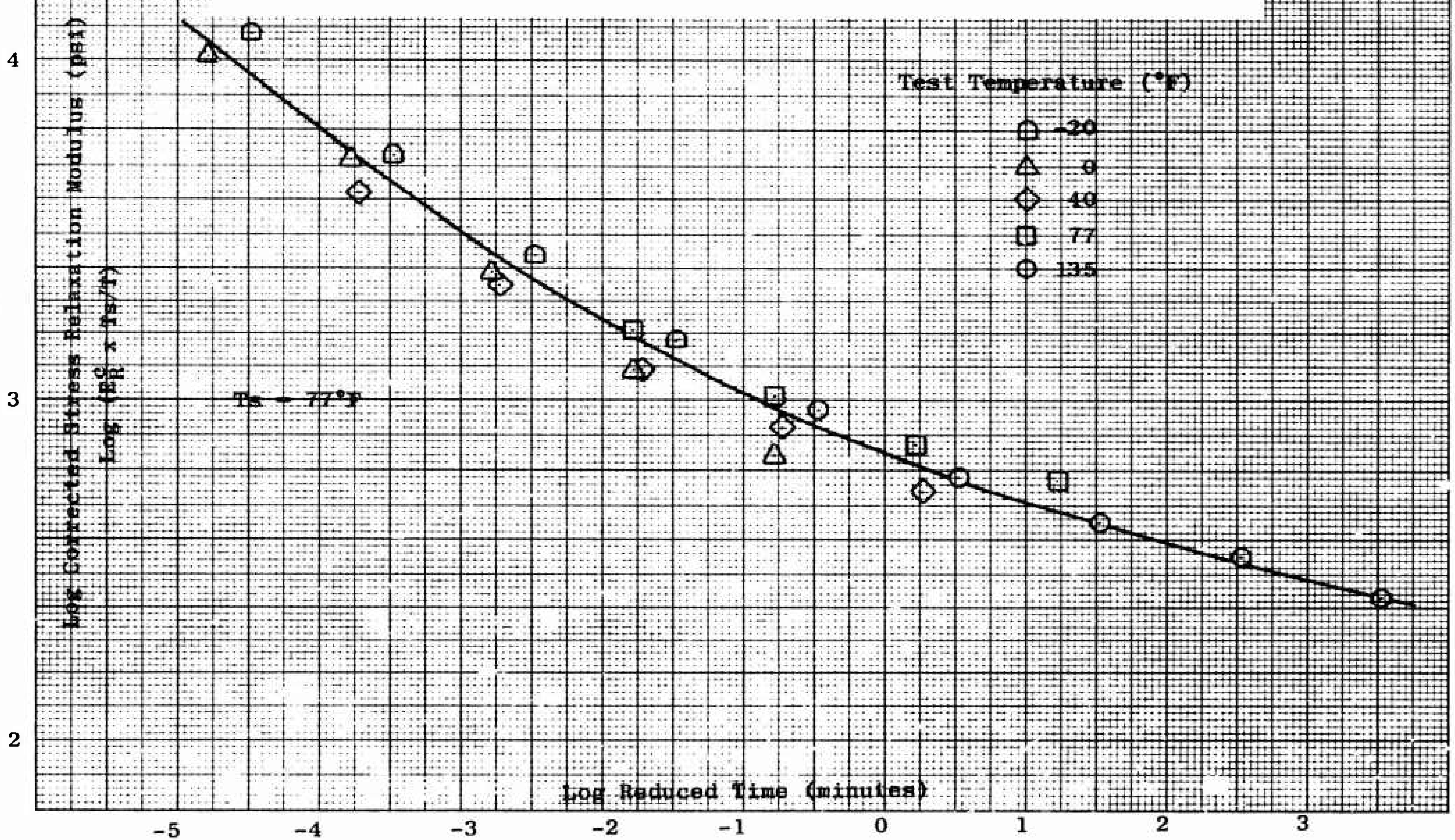


Figure 13. Stress Relaxation Modulus Master Curve for TP-H1135 Propellant
Mix 8577001 Aged 4 Months at 135° F
Tested at 3% Strain and Ambient Pressure

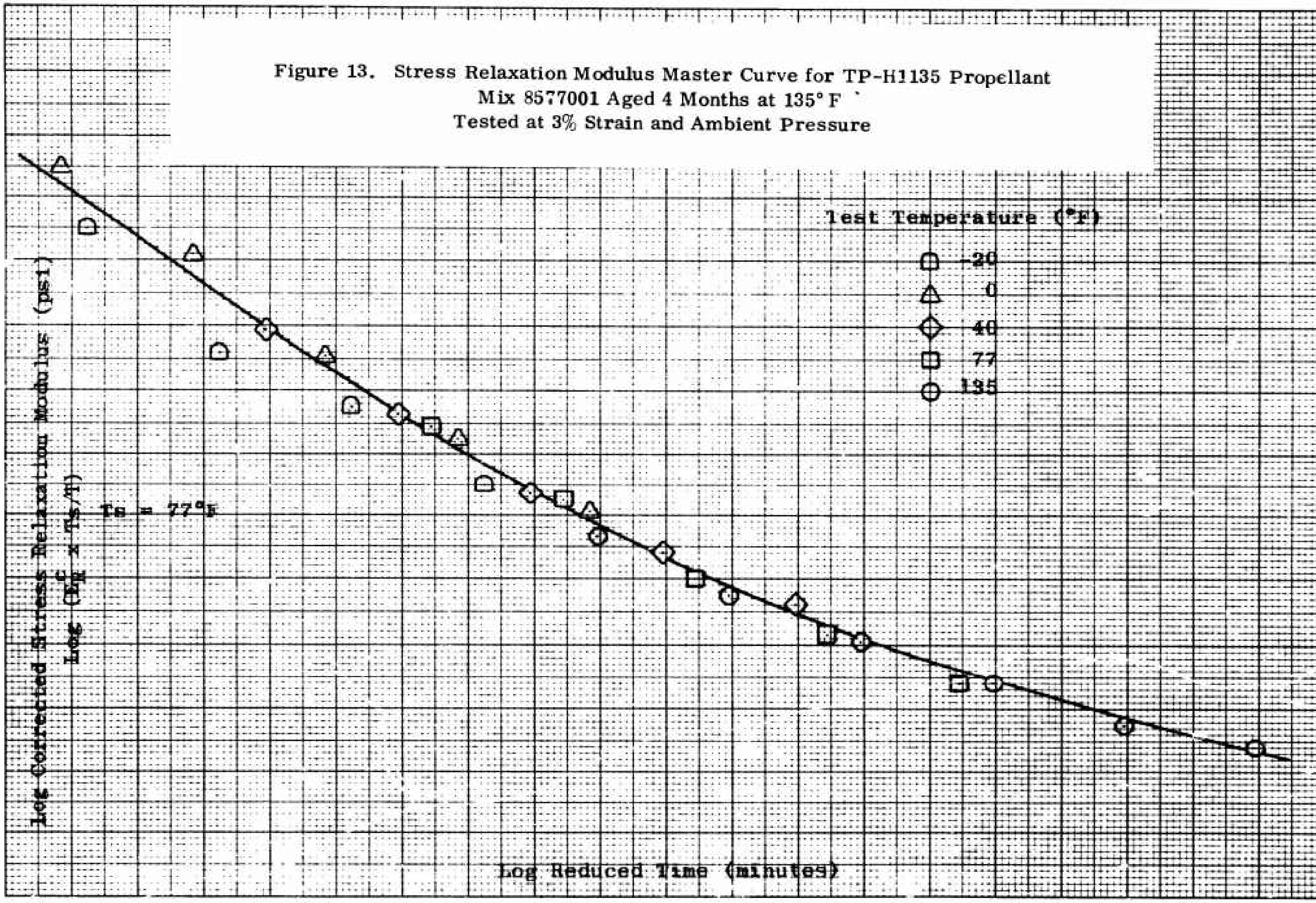
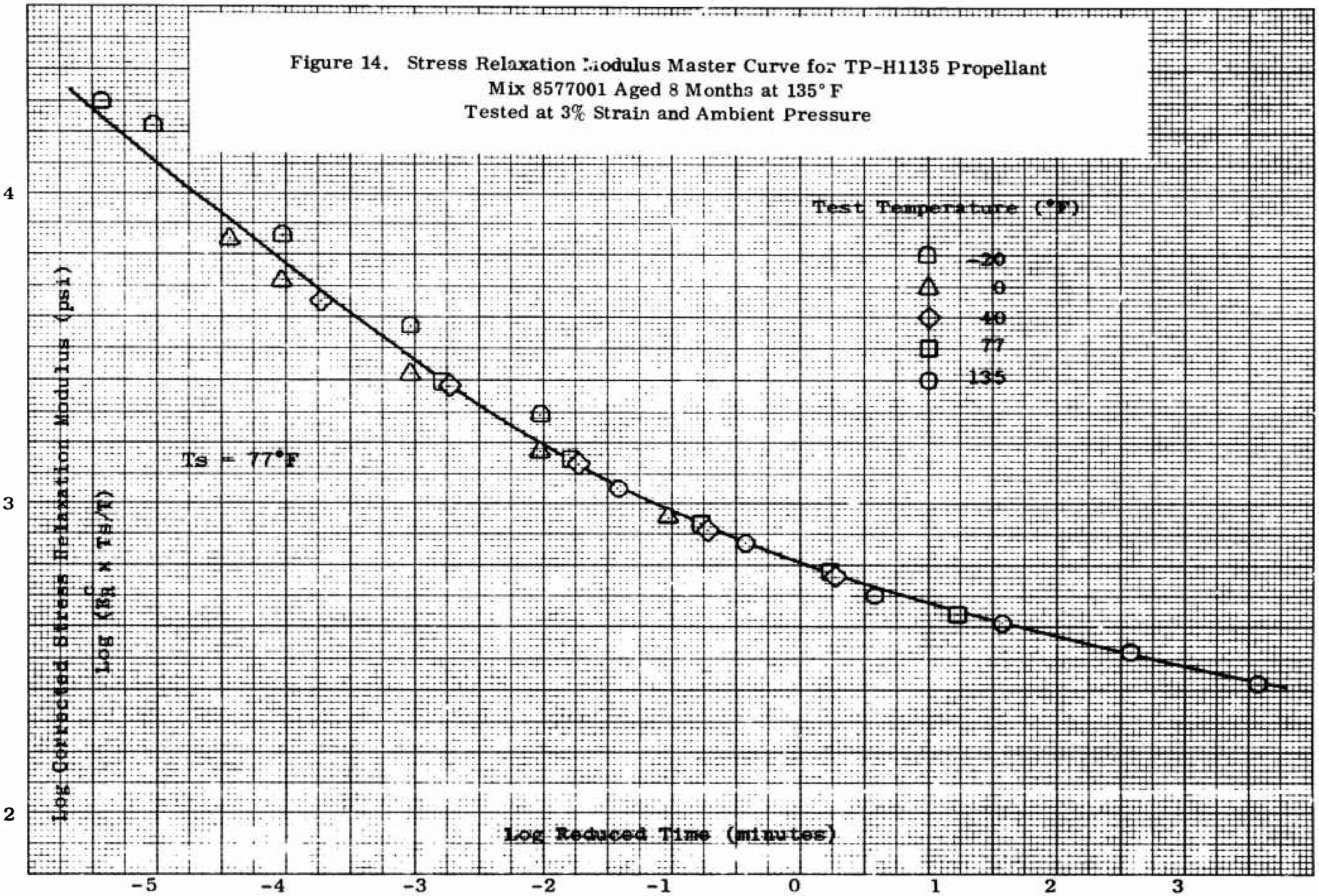


Figure 14. Stress Relaxation Modulus Master Curve for TP-H1135 Propellant Mix 8577001 Aged 8 Months at 135° F Tested at 3% Strain and Ambient Pressure



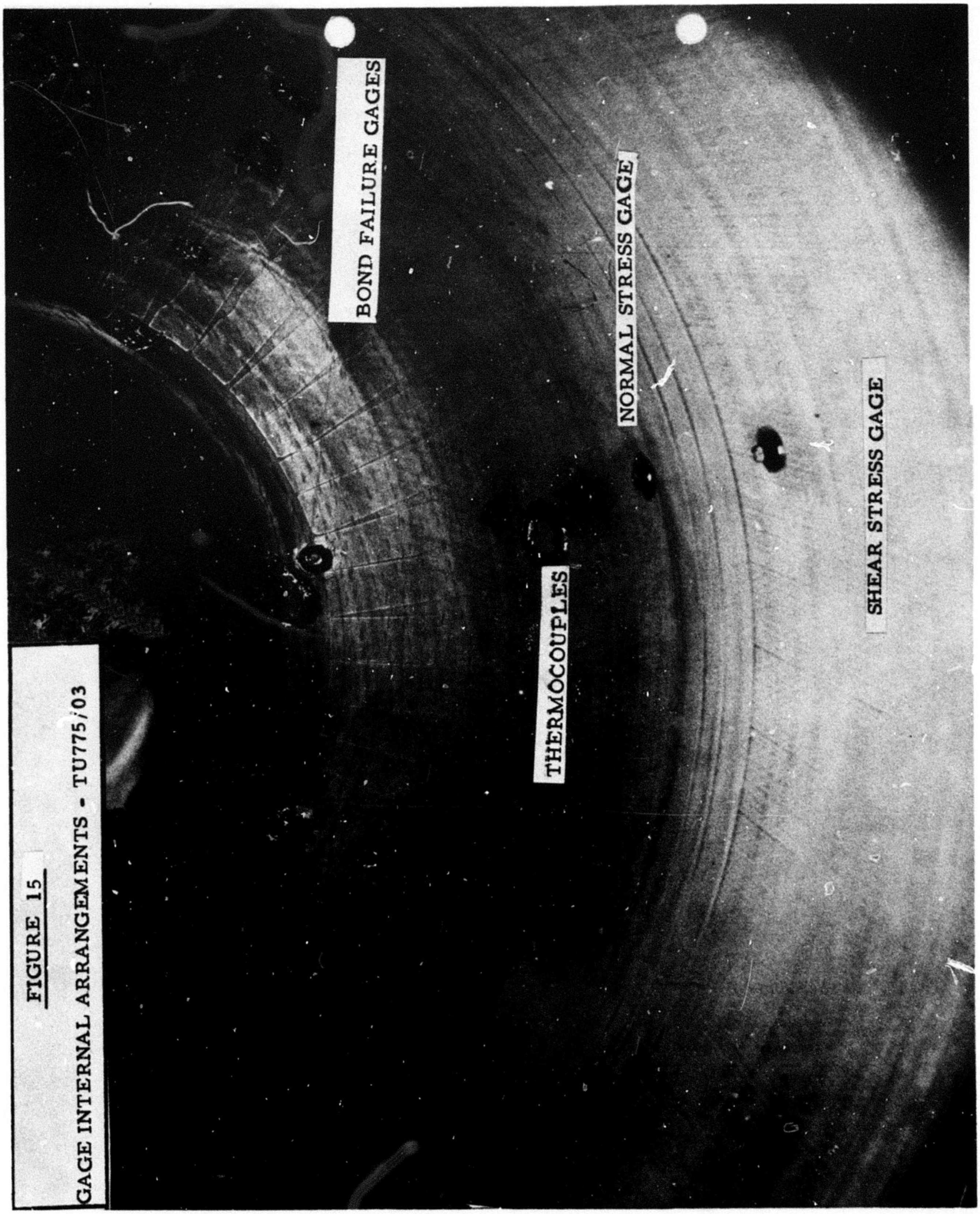


FIGURE 15

GAGE INTERNAL ARRANGEMENTS - TU775/03

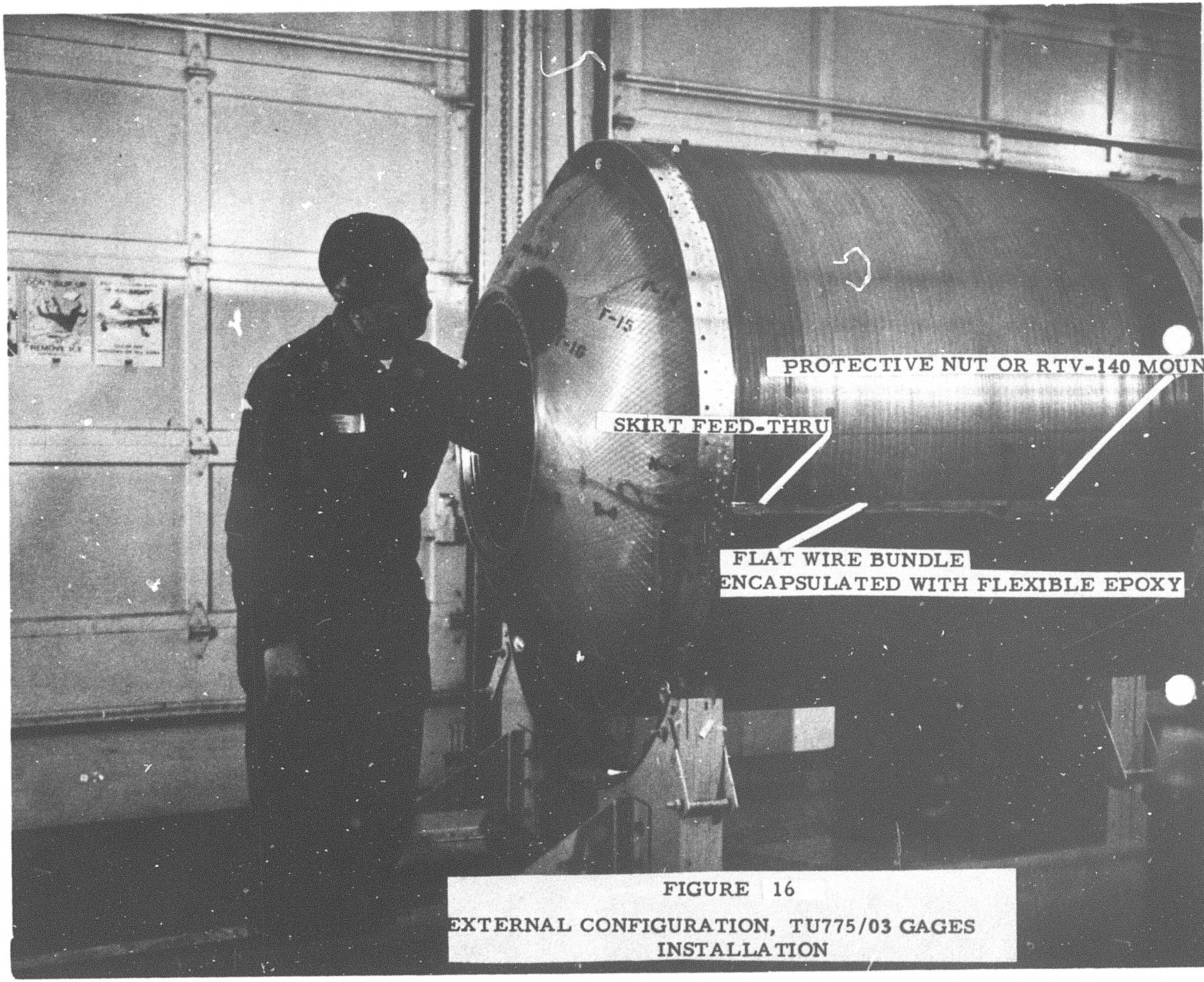


FIGURE 16

EXTERNAL CONFIGURATION, TU775/03 GAGES INSTALLATION

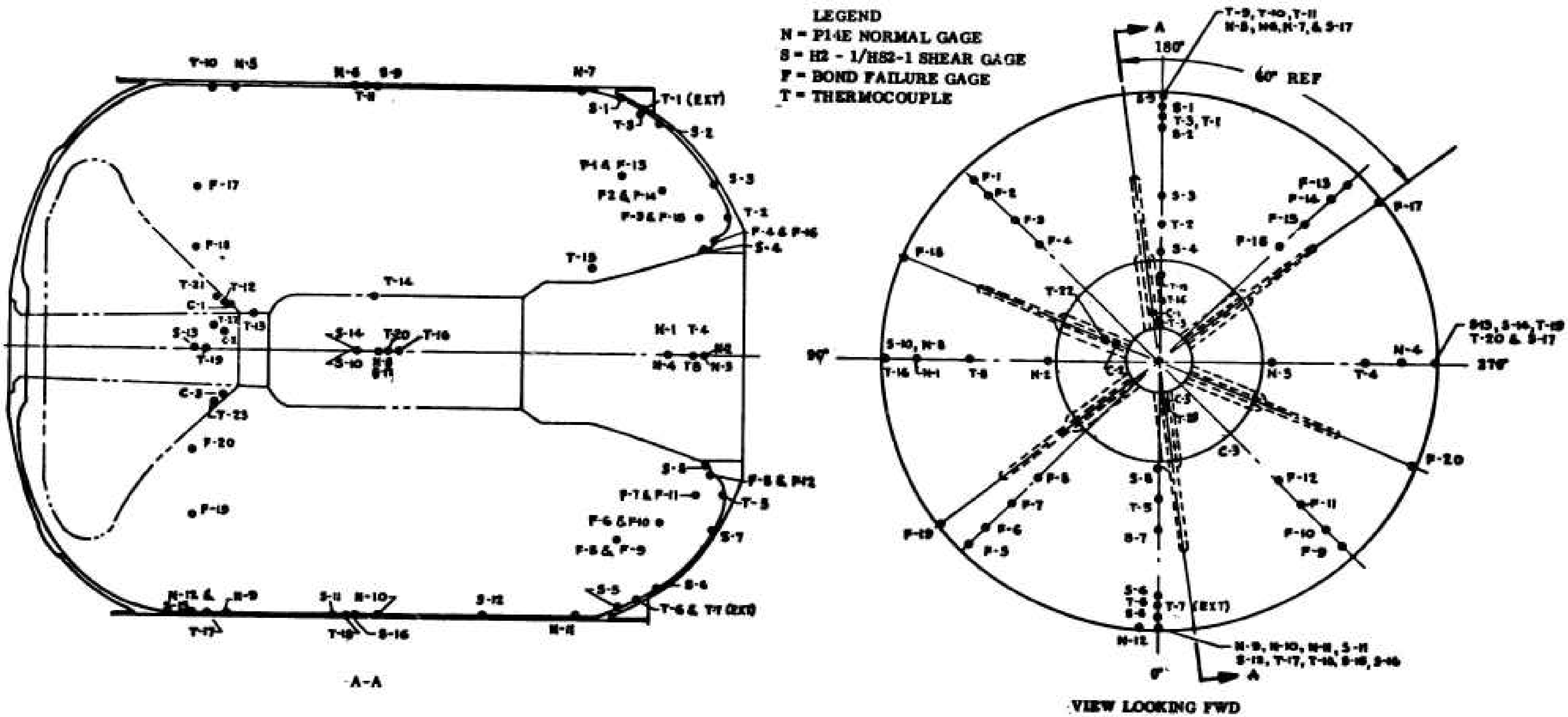


Figure 17
TU-775/03 Instrumented Motor

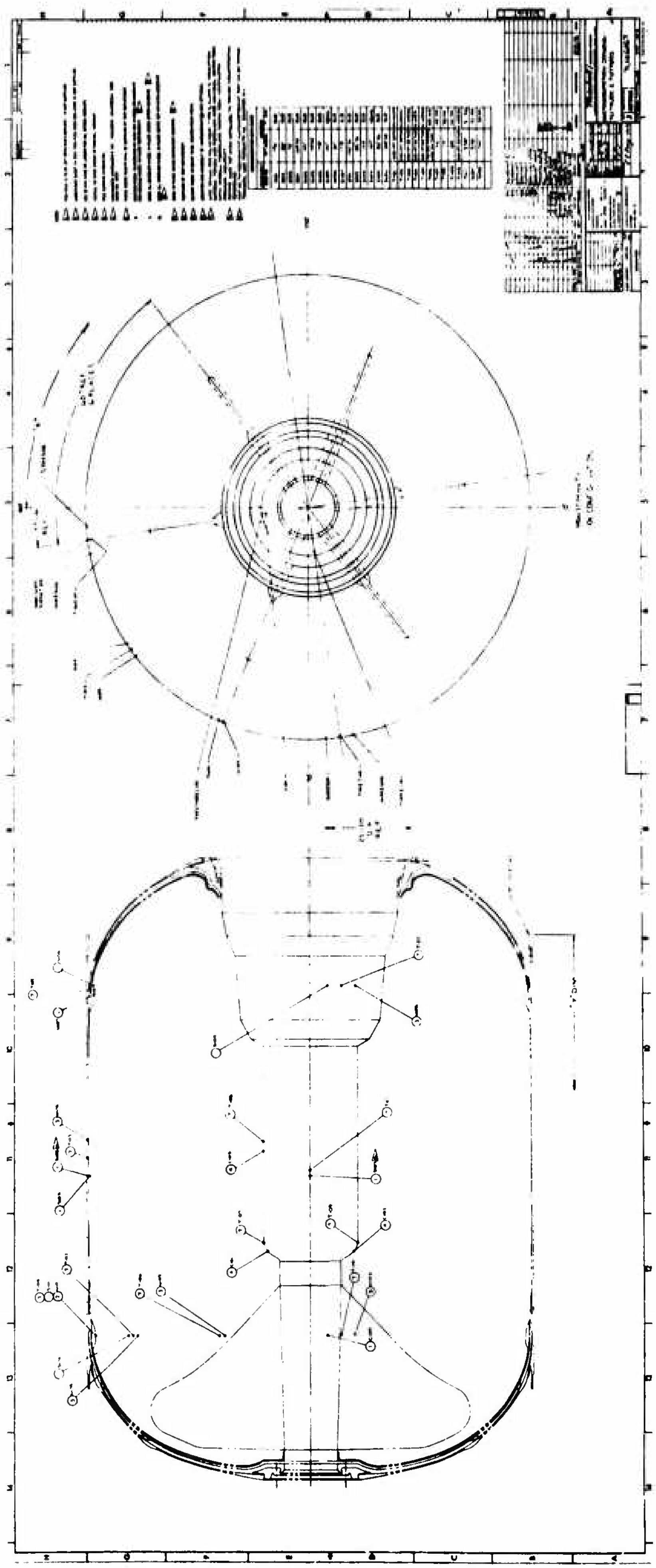


Figure 18
TU-775/02 Instrumentation

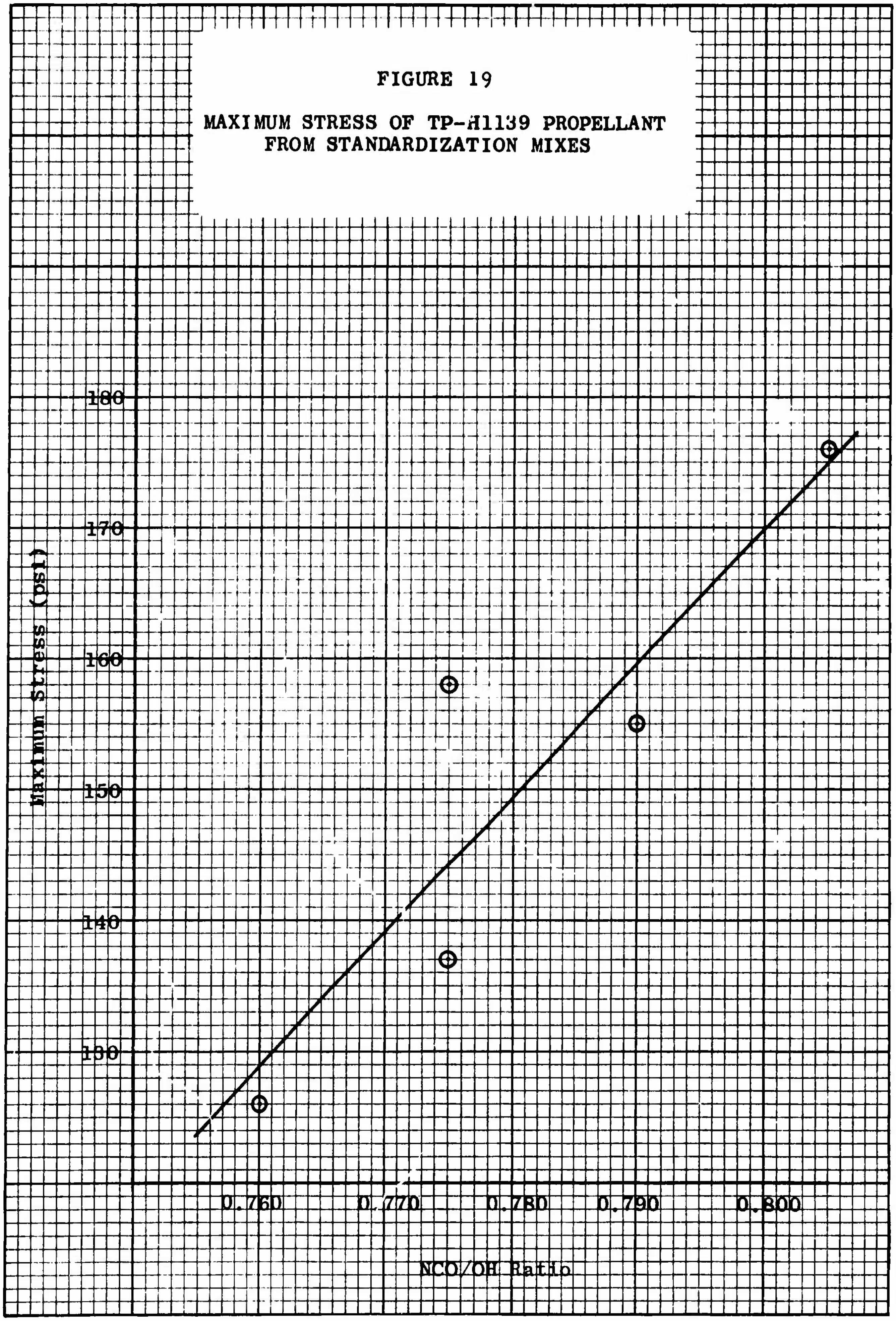


FIGURE 19

MAXIMUM STRESS OF TP-H1139 PROPELLANT
FROM STANDARDIZATION MIXES

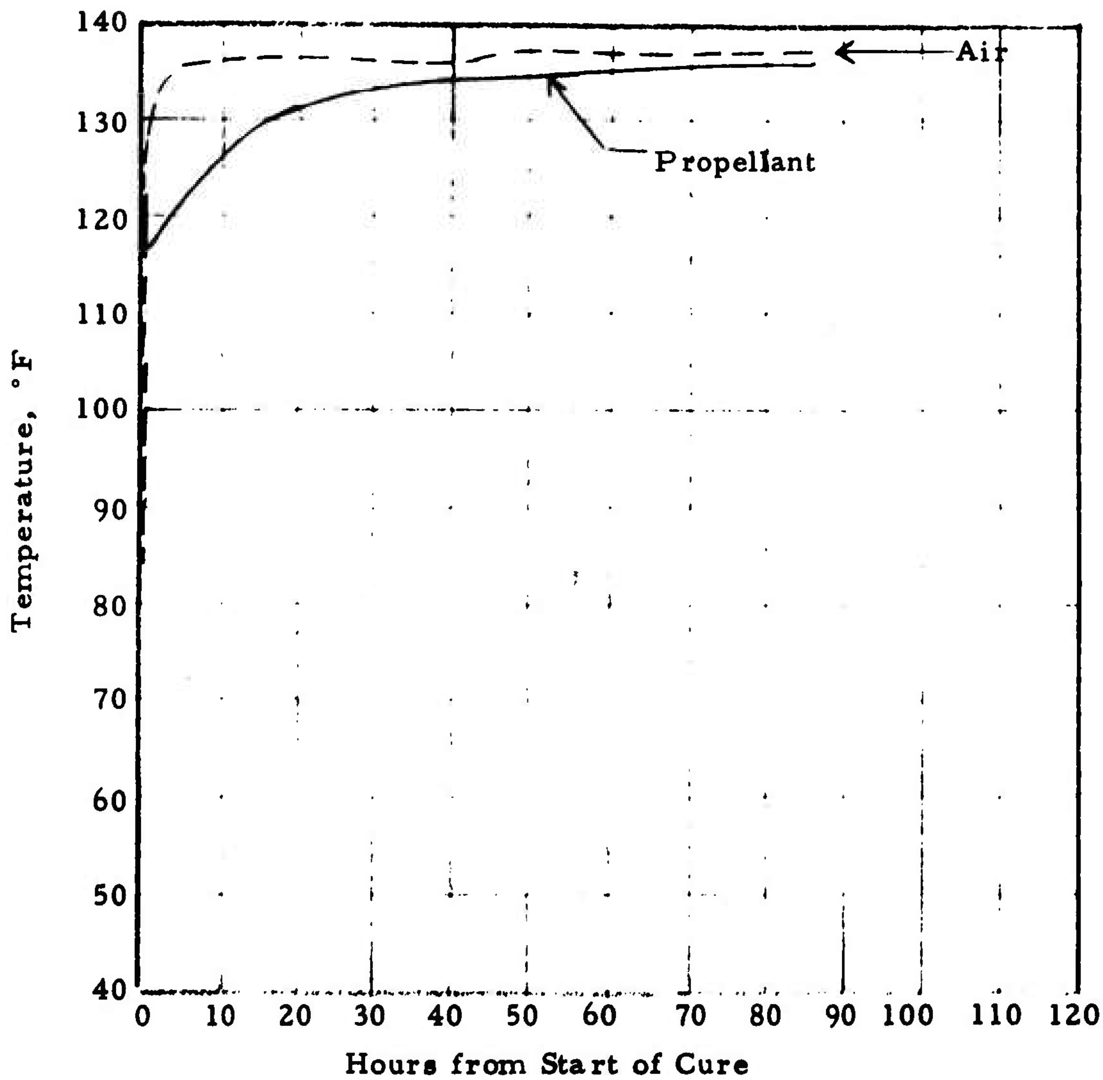


Figure 20

TU775/03 CURE PROFILE (U)

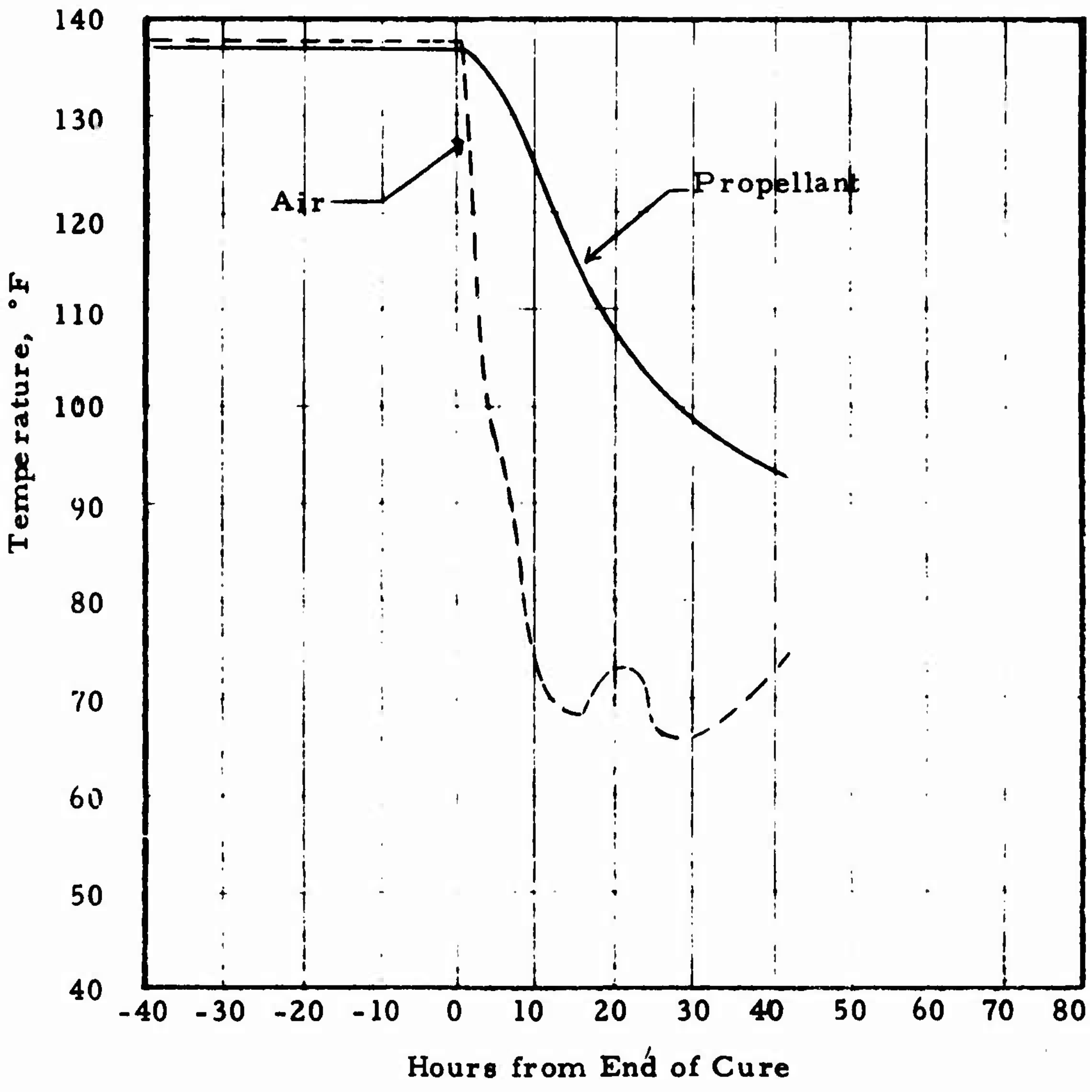


Figure 21

TU775/03 COOLDOWN PROFILE

TABLE 1

AGING OF DL-H271 90% SOLIDS PROPELLANT*

RDLNB F283-13

Aging Time (Weeks)	0	2	4	8	16	24	41
75°F Aging							
$E^{2.6}$ (psi)	371	493	499	508	689	670	596
σ_m (psi)	93	113	119	132	135	135	142
ϵ_{m+}^{t} (%)	34	36	42	40	33	33	34
ϵ_R^t (%)	42	43	46	48	42	42	39
135°F Aging							
$E^{2.6}$ (psi)	370	589	576	617	771	664	801
σ_m (psi)	96	134	137	152	156	166	187
ϵ_{m+}^{t} (%)	37	38	39	37	34	36	33
ϵ_R^t (%)	42	46	45	44	39	41	37

*2 in./min. Test Rate

TABLE 1 (Continued)

RDLNB F283-13

Aging Time (Weeks)	52	65	78	91	104	117
75°F Aging						
$E^{2.6}$ (psi)	815	750	720	657	622	697
σ_m (psi)	144	142	149	149	156	159
ϵ^t_{m+} (%)	34	34	35	36	39	37
ϵ^t_R (%)	37	40	44	42	44	40
135°F Aging						
$E^{2.6}$ (psi)	1100	948	1156	1026	1074	1128
σ_m (psi)	187	172	206	193	200	217
ϵ^t_{m+} (%)	32	30	28	32	32	33
ϵ^t_R (%)	36	34	32	38	34	37

TABLE 2

UNIAXIAL TENSILE PROPERTIES OF AGED ALTERNATE POLYMER PROPELLANT
DL-H306 Propellant, Mix 8737001

Aging Time (mo)	Aging Temp (°F)	Test Press (psi)	Test Temp (°F)	Crosshead Rate (in/min)	$E^{2.6}$ (psi)	σ_m (psi)	σ_m^c (psi)	ϵ_m^t (%)	ϵ_m^{tc} (%)	ϵ_R^t (%)
4	77	Amb	77	2	1260	163	210	30	32	33
				200	3800	284	399	38	42	47
			10	2	3850	305	388	29	29	34
			0	200	13900	666	728	9	11	11
			-40	2	12970	651	688	6	6	7
		800	77	2	1180	302	398	32	33	34
			10	2	6990	639	829	30	32	33
4	135	Amb	77	2	1860	187	240	33	34	35
				200	5760	273	364	30	32	32
			10	2	5330	328	440	34	36	40
			0	200	21900	762	830	8	9	9
			-40	2	15640	642	689	7	8	8
		800	77	2	1720	273	369	33	35	36
			10	2	6120	625	788	24	26	27

TABLE 3

UNIAXIAL TENSILE PROPERTIES OF TP-H1135 PROPELLANT
Mix 8577001 Aged 8 Months at 77°F

Test Temp (°F)	Crosshead Rate (in/min)	$E^{2.6}$ (psi)	σ_m (psi)	σ_m^c (psi)	$\sigma^c_{mxTs/T}$ (psi)	ϵ_m^t (%)	ϵ_m^{tc} (%)	ϵ_R^t (%)	Log Time (min)	Log a_T	Log t/a_T (min)
135	0.2	544	91	117	106	28	30	32	0.59	-2.0	2.59
77	0.2	782	123	157	157	27	30	32	0.59	0	0.59
	2	1350	152	195	195	27	31	35	-0.39		-0.39
	200	2800	286	389	389	34	33	46	-2.31		-2.31
40	2	2510	199	260	279	28	35	40	-0.34	1.5	-1.84
	20	3590	279	368	395	30	32	42	-1.38		-2.88
0	2	6840	338	433	505	26	32	39	-0.38	3.2	-3.58
	20	10600	482	601	701	23	29	31	-1.42		-4.62
	200	12000	636	719	839	12	16	17	-2.68		-5.88
-40	20	17800	759	807	1030	6	6	6	-2.11	5.0	-7.11
Pressurized at 800 psi											
77	2	1430	297	420	420	37	42	48	-0.26	0	-0.26
40	2	2310	420	584	627	36	40	46	-0.22	1.5	-1.72
0	2	5180	666	886	1030	28	33	38	-0.37	3.2	-3.57

TABLE 4

UNIAXIAL TENSILE PROPERTIES OF TP-H1135 PROPELLANT
Mix 8577001 Aged 8 Months at 135°F

Test Temp (°F)	Crosshead Rate (in/min)	$E^{2.6}$ (psi)	σ_m (psi)	σ_m^c (psi)	$\sigma_{mxTs/T}^c$ (psi)	ϵ_m^t (%)	ϵ_m^{tc} (%)	ϵ_R^t (%)	Log Time (min)	Log a_T	Log t/a_T (min)
135	0.2	532	98	127	115	29	31	33	0.61	-1.7	2.31
77	0.2	841	127	167	167	31	34	35	0.65	0	0.65
	2	1460	160	210	210	30	33	35	-0.37		-0.37
	200	3030	279	383	383	33	40	47	-2.28		-2.28
40	2	1620	201	274	294	35	38	43	-0.31	1.25	-1.56
	20	2960	282	376	404	32	34	40	-1.35		-2.60
0	2	4490	343	449	524	29	34	39	-0.35	2.75	-3.10
	20	6380	463	616	719	31	35	37	-1.34		-4.09
	200	10300	590	671	783	12	16	16	-2.68		-5.43
-40	20	15400	761	799	1020	5	5	5	-2.19	4.25	-6.44
Pressurized at 800 psi											
77	2	1060	281	380	380	35	37	39	-0.32	0	-0.32
40	2	3300	446	592	636	32	34	37	-0.35	1.25	-1.60
0	2	6050	684	874	1020	28	29	30	-0.42	2.75	-3.17

TABLE 5

BIAXIAL TENSILE PROPERTIES OF TP-H1135 PROPELLANT
Mix 8577001 Aged at 77°F

Aging Time (mo)	Test Temp (°F)	Crosshead Rate (in/min)	σ_m (psi)	$\sigma_m x T_s/T$ (psi)	ϵ_m (%)	Log Time (min)	Log a_T	Log t/a_T (min)
0	140	0.1	86	77	31	0.67	-1.50	2.17
		1.0	100	89	30	-0.35		1.15
	120	0.1	89	76	30	0.65	-1.10	1.75
		1.0	109	101	29	-0.36		0.74
	77	0.1	106	106	32	0.68	0	0.68
		1.0	136	136	32	-0.32		-0.32
	40	1.0	181	194	30	-0.35	1.13	-1.48
	0	1.0	365	425	10	-0.82	2.75	-3.57
		10	496	577	13	-1.71		-4.46
	-40	10	856	1090	6	-2.05	4.70	-6.75
1	77	1.0	155	155	34	-0.29	0	-0.29
	0	1.0	317	369	17	-0.59	2.75	-3.34
		10	475	552	9	-1.87		-4.62
	-40	10	747	952	8	-1.92	4.70	-6.62
2	77	1.0	141	141	28	-0.38	0	-0.38
	0	1.0	325	379	13	-0.71	2.75	-3.46
		10	486	567	14	-1.68		-4.43
	-40	10	847	1080	6	-2.05	4.70	-6.75
4	77	1.0	149	149	30	-0.35	0	-0.35
	0	1.0	330	385	17	-0.59	2.75	-3.34
		10	479	559	15	-1.65		-4.40
	-40	10	801	1020	7	-1.98	4.70	-6.68
8	77	1.0	148	148	30	-0.35	0	-0.35
	0	1.0	300	350	29	-0.36	2.75	-3.11
		10	487	568	14	-1.68		-4.43
	-40	10	703	899	3	-2.35	4.70	-7.05

TABLE 6

BIAXIAL TENSILE PROPERTIES OF TP-H1135 PROPELLANT
Mix 8577001 Aged at 135°F

Aging Time (mo)	Test Temp (°F)	Crosshead Rate (in/min)	σ_m (psi)	$\sigma_{m} xT_s/T$ (psi)	ϵ_m (%)	Log Time (min)	Log a_T	Log t/a_T (min)
0	(See 77°F Aging Data, Table IV)							
1/2	77	1.0	149	149	30	-0.35	0	-0.35
	0	1.0	325	378	18	-0.57	2.75	-3.32
		10	469	545	9	-1.87		-4.62
	-40	10	856	1090	7	-1.98	4.70	-6.68
1	77	1.0	157	157	32	-0.32	0	-0.32
	0	1.0	347	404	19	-0.55	2.75	-3.30
		10	527	613	8	-1.92		-4.67
	-40	10	835	1060	8	-1.92	4.70	-6.62
2	77	1.0	148	148	26	-0.41	0	-0.41
	0	1.0	321	375	--	--	2.75	--
		10	479	559	9	-1.87		-4.62
	-40	10	794	1020	11	-1.78	4.70	-6.48
4	77	1.0	167	167	23	-0.46	0	-0.46
	0	1.0	329	384	26	-0.41	2.75	-3.16
		10	494	576	6	-2.05		-4.80
	-40	10	751	961	--	--	4.70	--
8	77	1.0	148	148	29	-0.36	0	-0.36
	0	1.0	323	377	33	-0.31	2.75	-3.06
		10	479	559	26	-1.41		-4.16
	-40	10	848	1080	6	-2.05	4.70	-6.75

TABLE 7

STRESS RELAXATION MODULUS OF TP-H1135 PROPELLANT
Mix 8577001 Aged 4 Months at 77°F
Tested at 3% Strain and Ambient Pressure

Test Temp (°F)	Log Time (min)	E_R^c (psi)	$E_R^c x T_s/T$ (psi)	Log $(E_R^c x T_s/T)$ (psi)	Log a_T	Log t/a_T (min)
-20	-1.78	10300	12600	4.10	3.2	-4.98
	-0.78	4070	4970	3.70		-3.98
	0.22	1840	2250	3.35		-2.98
	1.22	928	1130	3.05		-1.98
0	-2.78	8950	10450	4.02	2.5	-5.28
	-1.78	4530	5290	3.72		-4.28
	-0.78	2170	2540	3.40		-3.28
	0.22	1280	1500	3.18		-2.28
	1.22	660	771	2.89		-1.28
40	-2.78	3800	4080	3.61	1.2	-3.98
	-1.78	2030	2180	3.34		-2.98
	-0.78	1060	1140	3.06		-1.98
	0.22	668	718	2.86		-0.98
	1.22	422	453	2.66		0.02
77	-2.78	1860	1860	3.27	0	-2.78
	-1.78	1150	1150	3.06		-1.78
	-0.78	670	670	2.83		-0.78
	0.22	449	449	2.65		0.22
	1.22	319	319	2.50		1.22
135	-2.78	964	870	2.94	-1.5	-1.28
	-1.78	623	562	2.75		-0.28
	-0.78	417	377	2.58		0.72
	0.22	303	273	2.44		1.72
	1.22	239	215	2.33		2.72
	2.22	194	175	2.24		3.72

TABLE 8

STRESS RELAXATION MODULUS OF TP-H1135 PROPELLANT
Mix 8577001 Aged 8 Months at 77°F
Tested at 3% Strain and Ambient Pressure

Test Temp (°F)	Log Time (min)	E_R^c (psi)	$E_R^c x T_s/T$ (psi)	Log ($E_R^c x T_s/T$) (psi)	Log a_T	Log t/a_T (min)
-20	-2.18	13900	17000	4.23	3.4	-5.58
	-1.78	10800	13100	4.12		-5.18
	-0.78	4870	5940	3.77		-4.18
	0.22	2440	2980	3.47		-3.18
	1.22	1440	1760	3.25		-2.18
0	-2.18	6660	7770	3.89	2.6	-4.78
	-1.78	4890	5700	3.76		-4.38
	-0.78	2400	2800	3.45		-3.38
	0.22	1360	1590	3.20		-2.38
	1.22	798	932	2.97		-1.38
40	-2.78	3900	4190	3.62	1.2	-3.98
	-1.78	2170	2330	3.37		-2.98
	-0.78	1190	1280	3.11		-1.98
	0.22	744	799	2.90		-0.98
	1.22	504	541	2.73		0.02
77	-2.78	2160	2160	3.33	0	-2.78
	-1.78	1240	1240	3.09		-1.78
	-0.78	742	742	2.87		-0.78
	0.22	504	504	2.70		0.22
	1.22	384	384	2.58		1.22
135	-2.78	1220	1100	3.04	-1.1	-1.68
	-1.78	815	736	2.87		-0.68
	-0.78	553	499	2.70		0.32
	0.22	414	374	2.57		1.32
	1.22	325	293	2.47		2.32

TABLE 9

STRESS RELAXATION MODULUS OF TP-H1135 PROPELLANT
Mix 8577001 Aged 2 Months at 135°F
Tested at 3% Strain and Ambient Pressure

Test Temp (°F)	Log Time (min)	E_R^c (psi)	$E_R^c xTs/T$ (psi)	Log ($E_R^c xTs/T$) (psi)	Log a_T	Log t/a_T (min)
-20	-1.78	9860	12000	4.08	2.7	-4.48
	-0.78	4370	5340	3.73		-3.48
	0.22	2240	2730	3.44		-2.48
	1.22	1240	1510	3.18		-1.48
0	-2.78	8730	10200	4.01	2.0	-4.78
	-1.78	4520	5280	3.72		-3.78
	-0.78	2110	2460	3.39		-2.78
	0.22	1070	1240	3.09		-1.78
	1.22	598	698	2.84		-0.78
40	-2.78	3860	4150	3.62	0.95	-3.73
	-1.78	2110	2260	3.35		-2.73
	-0.78	1140	1230	3.09		-1.73
	0.22	769	826	2.92		-0.73
	1.22	506	544	2.74		0.27
77	-2.78	2580	2580	3.41	0	-2.78
	-1.78	1630	1630	3.21		-1.78
	-0.78	1020	1020	3.01		-0.78
	0.22	743	743	2.87		0.22
	1.22	591	591	2.77		1.22
135	-2.78	1570	1420	3.15	-1.3	-1.48
	-1.78	1020	923	2.97		-0.48
	-0.78	674	608	2.78		0.52
	0.22	500	451	2.65		1.52
	1.22	390	352	2.55		2.52
	2.22	295	266	2.43		3.52

TABLE 10

STRESS RELAXATION MODULUS OF TP-H1135 PROPELLANT
Mix 8577001 Aged 4 Months at 135°F
Tested At 3% Strain and Ambient Pressure

Test Temp (°F)	Log Time (min)	E_R^c (psi)	$E_R^c xTs/T$ (psi)	Log $(E_R^c xTs/T)$ (psi)	Log a_T	Log t/a_T (min)
-20	-2.78	10800	13200	4.12	3.6	-6.38
	-1.78	6450	7870	3.90		-5.38
	-0.78	2730	3330	3.52		-4.38
	0.22	1830	2230	3.35		-3.38
	1.22	1040	1270	3.10		-2.38
0	-2.78	10700	12500	4.10	2.8	-5.58
	-1.78	5690	6640	3.82		-4.58
	-0.78	2760	3220	3.51		-3.58
	0.22	1520	1770	3.25		-2.58
	1.22	879	1030	3.01		-1.58
40	-2.78	3630	3890	3.59	1.25	-4.03
	-1.78	2010	2160	3.33		-3.03
	-0.78	1100	1180	3.07		-2.03
	0.22	705	757	2.88		-1.03
	1.22	488	524	2.72		-0.03
77	-2.78	1960	1960	3.29	0	-2.78
	-1.78	1130	1130	3.05		-1.78
	-0.78	631	631	2.80		-0.78
	0.22	425	425	2.63		0.22
	1.22	304	304	2.48		1.22
135	-2.78	952	859	2.93	-1.25	-1,53
	-1.78	621	561	2.75		-0.53
	-0.78	447	403	2.61		0.47
	0.22	336	304	2.48		1.47
	1.22	262	237	2.37		2.47
	2.22	212	192	2.28		3.47

TABLE 11

STRESS RELAXATION MODULUS OF TP-H1135 PROPELLANT
Mix 8577001 Aged 8 Months at 135°F
Tested at 3% Strain and Ambient Pressure

Test Temp (°F)	Log Time (min)	E_R^c (psi)	E_R^cxTs/T (psi)	Log (E_R^cxTs/T) (psi)	Log a_T	Log t/a_T (min)
-20	-2.18	16400	20100	4.30	3.25	-5.43
	-1.78	13500	16500	4.22		-5.03
	-0.78	5880	7180	3.86		-4.03
	0.22	3080	3760	3.57		-3.03
	1.22	1590	1940	3.29		-2.03
0	-2.18	6000	7000	3.85	2.25	-4.43
	-1.78	4450	5200	3.72		-4.03
	-0.78	2250	2630	3.42		-3.03
	0.22	1260	1470	3.17		-2.03
	1.22	762	889	2.95		-1.03
40	-2.78	4120	4430	3.65	0.95	-3.73
	-1.78	2230	2390	3.38		-2.73
	-0.78	1240	1340	3.13		-1.73
	0.22	765	822	2.91		-0.73
	1.22	540	580	2.76		0.27
77	-2.78	2470	2470	3.39	0	-2.78
	-1.78	1400	1400	3.15		-1.78
	-0.78	857	857	2.93		-0.78
	0.22	598	598	2.78		0.22
	1.22	434	434	2.64		1.22
135	-2.78	1240	1120	3.05	-1.35	-1.43
	-1.78	826	745	2.87		-0.43
	-0.78	561	506	2.70		0.57
	0.22	448	404	2.61		1.57
	1.22	363	327	2.52		2.57
	2.22	289	261	2.42		3.57

TABLE 12

TP-H1139 PROPELLANT ONE GALLON STANDARDIZATION MIXES
RDLNB F580-45 & 47

Compositions	Lot No.	1	2	3	4	5
R-45M	9986(901)-0011					
IPDI	9431-0006	12.000	12.000	12.000	12.000	12.000
HX-752	8408-0005					
Al	9004-0025	20.000	20.000	20.000	20.000	20.000
AP, 5μ	9023-0024					
AP, 90μ	9059-0011	68.000	68.000	68.000	68.000	68.000
AP, 200μ	9023-0024					
NCO/OH Ratio		0.775	0.790	0.805	0.775	0.760
End of Mix Viscosity (kp@°F)		6.1@125	4.8@134	5.1@134	5.1@133	4.8@137
Mechanical Properties (2 in/min)						
$E^{2.6}$ (psi)		838	840	943	799	673
σ_c^m (psi)		158	155	176	137	126
σ_t^m (psi)		229	227	250	205	193
ϵ_{m+}^{tc} (%)		41	44	39	47	51
ϵ_{m+}^{t} (%)		49	50	46	54	56
ϵ_R^t (%)		53	52	48	55	58